

APPLICATION OF OPTIMIZATION ALGORITHMS IN FIRE PROTECTION SYSTEMS

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ABSTRACT:

The paper discusses the problem of improving fire protection systems in operation or systems in the design phase by applying biologically inspired optimization algorithms. The application of various optimization algorithms is analyzed to improve the efficiency and performance of fire protection systems in terms of timely detection and localization of fires. Examples of optimization of various fire extinguishing systems are considered, such as stable fire suppression systems with water, smoke, and heat removal systems etc. The paper aims to provide an overview of recent research on fire protection system optimization, while also serving as an informative reference for future research in the field of fire protection.

Keywords: *fire protection systems, optimization algorithms, efficiency, fire suppression systems*

1. INTRODUCTION

Fire protection is a set of various measures and activities of preventive action, with the aim of timely detection, prevention of the occurrence and spread of fires, reduction of potential consequences to the smallest possible extent, effective fire extinguishing, determination of the methods and causes of fires and explosions, and above all, it aims to protect human lives and material goods. Therefore, in order to maintain a safe society, planning, preventive action, and coordination of fire and rescue resources are of great importance. In order to more effectively plan, design, and manage fire protection resources, various tools based on optimization are often used as support [1].

Optimization itself is a complex process of determining the optimal solution and is implemented in several phases and decision-making levels. The optimization process can be divided into several steps, which are performed sequentially: problem definition, problem formulation, solving a mathematical model of the problem, solution implementation, and validation of the obtained optimization results. In the last few decades, and especially in the late 20th and early 21st centuries, algorithms have been used

that enable the solution of complex optimization problems in an efficient manner [2]. These algorithms are called metaheuristic algorithms and are often inspired by phenomena and processes in nature, i.e., they imitate good characteristics and phenomena from nature. According to research in [3], there are more than 500 metaheuristic algorithms that have been developed to date, and over 350 have been presented in the last ten years. The above data on the number of developed metaheuristic optimization algorithms is not final, but there is constant work on improving existing ones and creating new algorithms, where nature is an inexhaustible source of inspiration for researchers.

A review of relevant literature has shown that, depending on the complexity, fire protection system optimization is most often performed in the following types of facilities: industrial facilities (production and logistics), public facilities (universities, libraries, museums, stadiums and metro stations), transport infrastructure (tunnels) and residential and commercial facilities (high-rise residential and commercial buildings and supermarkets). In addition to optimizing fire protection systems, optimization algorithms are also used in the modeling and optimization of fire routes and evacuation routes from the facility.

2. OPTIMIZATION IN FIRE PROTECTION SYSTEMS

2.1. Optimization of fire detection systems in warehouses

Early detection of a fire, as well as its timely localization using a fire protection system, is an integral condition for avoiding more serious damage to the warehouse and potential human casualties. Depending on the selected type and type of fire detection and alarm detectors used to protect the corresponding premises and locations where they are installed, the operating time of all elements of the fire alarm system will depend. Based on relevant scientific sources, it is concluded that there is no comprehensive approach to choosing the optimal layout of contents in warehouses. Also, there are no relevant works in the available literature that relate to the optimal layout of fire alarm detectors in warehouses, depending on the fire load. In this regard, the aim of the paper [4] is to determine the optimal operating time of different types of fire detectors depending on the type of flammable material, i.e., its combustion rate, the distance and height at which the fire detectors are installed about the potential location of the occurrence. The results of the experiments showed that smoke detectors and aspiration systems for extinguishing fires are the most effective in warehouses. Based on the results of the complete experiment, nonlinear empirical dependencies were constructed for determining the operating time of smoke fire detectors from the listed factors. The mentioned empirical dependencies allow the selection of fire detectors and their optimal placement in the warehouse space. The use of the obtained dependencies allows reducing the operating time of fire detectors by 14 seconds compared to the classic approach to installing fire detectors based on current building regulations.

2.2. Optimization of fire extinguishing strategies in process plants

Effective fire suppression and evacuation are integral parts of process plant emergency response plans, all with the aim of protecting people and property in the event of a major fire. Assuming that firefighters responding to a process plant fire have sufficient fire extinguishing agents at their disposal, they must cool all tanks and burning equipment. However, when the number of parts of a process plant that are burning or affected by fire exceeds the available fire extinguishing resources, firefighters must decide how to optimally allocate resources to meet safety objectives. To facilitate such decisions, in [5], an appropriate methodology for effective fire suppression in cases where fire departments do not have sufficient fire extinguishing agents at their disposal is developed. The methodology includes two safety objectives based on optimal firefighting strategies: ensuring the safety of evacuees and reducing the risk of a domino effect (Fig. 1). This demonstrates the importance and advantages of multi-criteria (multi-objective) optimization over single-criteria optimization, especially in the specific case of human and property safety.

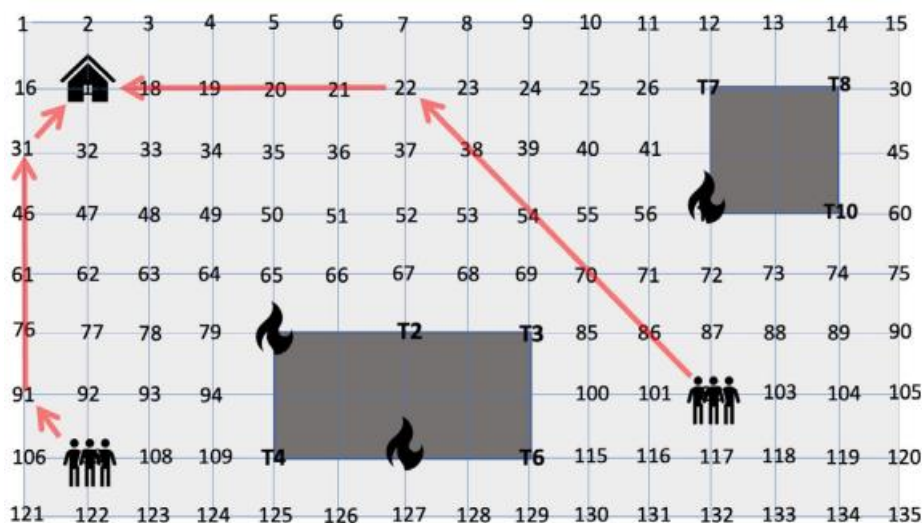


Fig. 1. Modeling the process plant for the given tanks affected by the fire - T1, T5, and T9. (Evacuation routes from the process plant are marked with red arrows for each operational unit.) [5]

2.3. Optimization of evacuation routes in supermarkets

Evacuation routes that are an integral part of the evacuation plan are considered fixed because they do not take into account the impact of harmful combustion products generated during a fire on the efficiency of evacuation. The impact of harmful combustion

products is most often reflected in their impact on the speed of evacuation due to the large amount of toxic substances contained in the smoke. To solve this problem, an improved ant colony optimization algorithm (IACO) was proposed in the paper [6] in order to determine the optimal evacuation route in a supermarket building, under unfavorable conditions caused by elevated temperature and emission of harmful combustion products. In the first phase, a simulation of a real fire scenario is performed using simulation software (PyroSim) with real-time temperature and carbon monoxide (CO) concentration at multiple locations in the building. After the simulation is completed, the evacuation route is optimized using the (IACO) algorithm, taking into account harmful combustion products. Unlike the route obtained using the software (Pathfinder), the route obtained by optimization can effectively avoid parts of the building with heavy fire loads and reduce potential casualties. Finally, based on the obtained optimization results, an evacuation route can be generated in a three-dimensional environment.

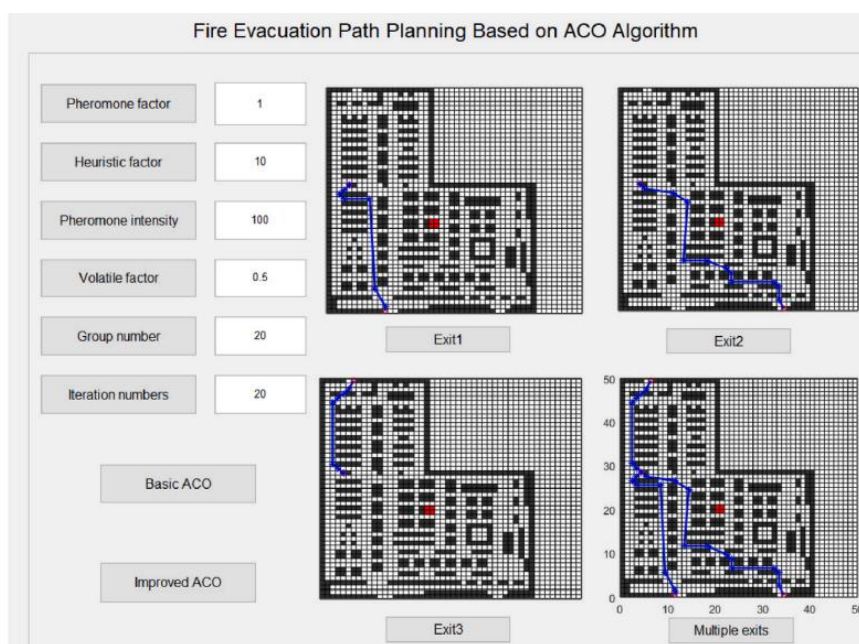


Fig. 2. Presentation of the path planning results [6]

2.4 Application of optimization when determining the predictive behavior of tunnel fires

Fires occurring in tunnels have attracted the attention of researchers and experts in the field of fire protection because their occurrence causes large economic losses, material damage, and potential human casualties. The key steps in solving the above problem are

the assessment of the potential development, as well as a quick response in the event of a fire occurring in the tunnels. In the paper [7], a method for intelligently predicting the evolution of the fire state was developed based on an improved fire simulation curve, which was created using data resulting from the optimization process using the particle swarm algorithm. It was experimentally proven that the proposed method can effectively represent the development behavior of a typical fire in a tunnel. More precisely, the method is accurate in a wide range of conditions and factors affecting the simulation flow. The proposed method has a wide range of applications, its application can avoid complicated temperature expansion mechanisms, which represent an additional burden as an additional workload for prior information and the limitation of a specific fire.

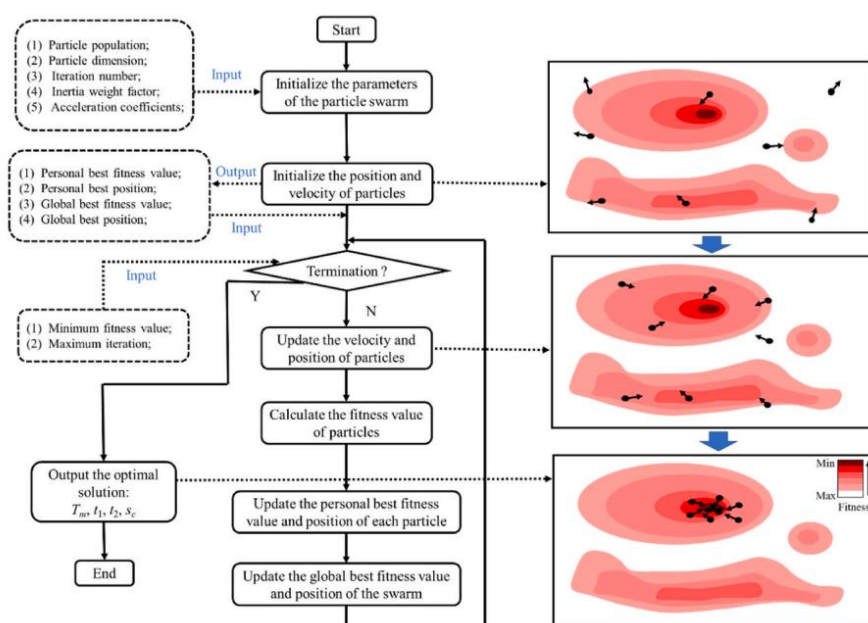


Fig. 3. Flowchart of the PSO algorithm [7]

2.5 Determining and selecting the location of potential fire protection sites for mega projects

The construction sites of large (mega) projects often harbor great fire hazards. In order to improve the ability to respond promptly to emergencies at the construction site of a mega-project in Sichuan Province (China), in the paper [8], in the first phase, the number of required fire protection locations on the construction site was estimated. In the second phase, the risk assessment method of the construction site conditions was used to assess the risk and determine the risk level. In the next phase, a multi-objective model for

optimizing the selection of fire protection points was established according to the construction site layout criteria and technical fire protection criteria, including the main factors of economy, distance, time, and coverage of fire protection points. Using the particle swarm optimization algorithm to solve the aforementioned multi-objective fire protection site selection model, a wide range of fire protection site selection schemes were obtained. Finally, the best location was selected using the Analytic Hierarchy Process (AHP).

3. CONCLUSION

Given that the optimization process speeds up the calculation of complex tasks and problems, it is not surprising that the application of optimization algorithms has been expanding rapidly in the last few decades. This paper presents examples of the application of optimization algorithms in the field of fire protection. By reviewing representative examples, it is evident that the integration of optimization algorithms has yielded significant results, accelerating progress in fire protection methodologies.

ACKNOWLEDGEMENT

This work has been supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia, through the Contract for the scientific research financing in 2025, 451-03-137/2025-03/200108 to build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation which is the ninth goal of the UN's 2030 Agenda of Sustainable development.

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